

Computational Design of Nebuta-like Paper-on-Wire Artworks

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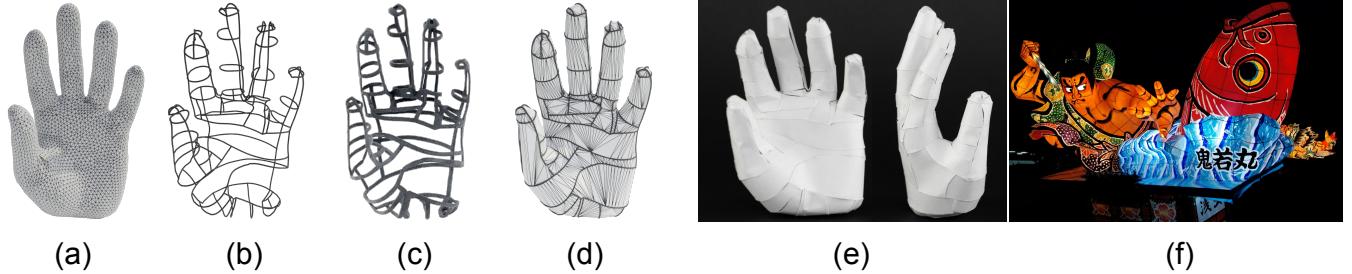


Figure 1: Our method takes a 3D model as the input (a), extracts the 3D wireframe (b) and computes the corresponding 2D pattern. (c) is the 3D printed plastic wireframe; (d) is the approximated developable patches; (e) is the fabricated model from two viewpoints using washi paper; (f) shows a Nebuta exhibited in the 2012 Asamushi Onsen Nebuta Festival © 663highland, licensed under CC-BY.*

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1 INTRODUCTION

Nebuta is an illuminated float made by covering a wireframe with brightly colored and painted paper, which is exclusively used in festivals in Aomori, Japan (Figure 1(f)). The design of the wireframe structure is challenging because one needs to balance the aesthetic goal and fabrication costs. This requires a level of artisanal skill that can only be honed through decades of experience; therefore, it is difficult for novices to master.

To address this issue, we propose a computational pipeline for designing Nebuta-like paper-on-wire artworks. We formulate aesthetics as shape similarity between the output piecewise developable patches and the input shape, and the fabrication cost as the number of developable pieces formed by the wire.

Existing developable approximation works either do not form a patch layout (e.g., [Binninger et al. 2021]) or do not encourage orthogonality of the wire crossing (e.g., [Zhao et al. 2022]). We thus have built our method upon the garment pattern generation algorithm proposed by [Pietroni et al. 2022]. Their approach employed a 3D garment surface shape as input and generated the 2D pattern by segmenting the surface into patches using a textile distortion

measure. In contrast, we applied a developable approximation measure to guide the segmentation process, considering that our target model consists of non-stretchable developable paper patches rather than stretchable textiles.

2 METHOD

Our method takes a surface mesh as input and proceeds with three steps based on [Pietroni et al. 2022]: (1) cross-field construction, (2) layout construction, and (3) patch flattening. Step 1 encourages the orthogonal crossing of wires. Step 2 first inserts paths across the surface based on the cross-field, then iteratively removes the added paths. To ensure the producibility of the layout, we impose constraints such that each patch is topologically equivalent to a disk and has at most five corners. Finally, Step 3 performs patch flattening onto a plane. While Step 1 remains unchanged from the original method, we have modified Steps 2 and 3.

The original method utilizes the textile-based distortion measure, and Steps 2 and 3 work to minimize the measure. However, unlike fabric, paper cannot undergo non-isometric deformations such as stretching and shearing. Therefore, we made two technical contributions:

- (1) We replaced the original distortion measure with the Hausdorff distance between the input surface and its developable approximation.
- (2) We introduced a new developable approximation algorithm that generates a triangulated strip that minimizes the Hausdorff distance.

Based on these two methods, in Step 2, We removed paths unless the approximation error of all patches remained below a heuristically predefined threshold. Also, we flattened each patch in Step 3 by recursively placing the developable approximation onto the plane without distortion. Below, we discuss the two contributions in detail.

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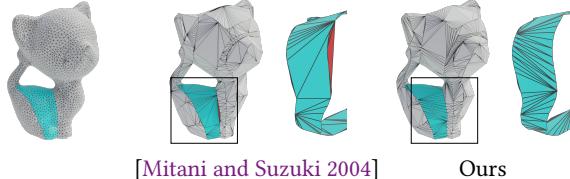


Figure 2: Our developable approximation method. For a given 3D shape (left), [Mitani and Suzuki 2004] can generate sharp creases in the approximated patch (middle, creases shown in red from a different viewpoint), while our method can avoid such creases (right).



Figure 3: The 3D printed plastic wireframe (left) and the bunny fabricated with washi (right).

Hausdorff distance. We define the developable approximation error as the one-sided discrete Hausdorff distance H_d between the original patch A and the approximated developable patch \hat{A} :

$$H_d(A, \hat{A}) = \max_{v \in A} \min_{f \in \hat{A}} \text{dist}(v, f)$$

where f denotes the triangle on the approximated developable patch \hat{A} and v denotes the vertex the original patch A .

Developable approximation. As for the developable approximation method, we first investigated [Mitani and Suzuki 2004]’s method to produce the strip-based developable surface for each patch. However, we found that their algorithm sometimes produces sharp creases and degenerate triangles due to its greedy search approach, as shown in Figure 2 middle. We thus propose a dynamic programming-based algorithm that considers all triangulation possibilities. More specifically, we gradually increase the number of consecutive vertices on the wire of a patch and search the minimal one-sided Hausdorff distance for every possible triangulation with the memory of previous triangulation results. Finally, we obtain the triangulation of the developable approximation with the smallest one-sided Hausdorff distance.

3 RESULTS

We evaluated the material costs (i.e., patch number and wire length) on five models from the dataset in [Pietroni et al. 2021] and compared the results with those obtained using the original method, which served as our baseline for evaluation. Also, as an ablation study, we compared our results with those obtained using the greedy algorithm [Mitani and Suzuki 2004] for developable approximation while using the same Hausdorff distance measure. To compare the effect on the number of patches while keeping the approximation error constant, we carefully selected the threshold so that the approximation error is in the range of [0.022, 0.026].

Table 1: Experiment Results.

Model	Patch Number ↓			Wire Length ↓		
	Ours	Baseline	Greedy	Ours	Baseline	Greedy
foot	18	39	21	7.3	9.7	8.3
3 holes	36	82	40	20.9	28.0	24.1
hand	54	98	51	16.4	22.0	16.5
cow	78	140	74	25.5	32.7	26.4
bunny	70	236	80	28.4	48.3	30.1
AVG	51.2	119.0	53.2	19.7	28.0	21.1

Table 1 shows the result of the quantitative comparison. The result shows that compared to the baseline or the greedy method, the proposed method achieves a similar approximation error with fewer patches and shorter wire lengths on average. We also fabricated two models (hand and bunny) as shown in Figure 1 and Figure 3, confirming that our pipeline produces visually pleasing artifacts.

4 CONCLUSION AND FUTURE WORK

We introduced a computational pipeline for designing Nebuta-like paper-on-wire artworks from the input 3D model. To balance the aesthetic goal and fabrication costs, we proposed the usage of Hausdorff distance and proposed a novel developable approximation method, which reduces the fabrication cost. Also, we tested multiple models to demonstrate the practicability of our pipeline. For future work, we aim to further optimize the wireframe by taking into account the texture and lighting conditions within the Nebuta. This will ensure an aesthetically appealing illuminated texture while preventing the shadow of the wire from being cast outward. Eventually, we hope to utilize our method in the real Nebuta manufacturing process.

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